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(54) **FREQUENCY CONTROL METHOD AND FREQUENCY CONTROL SYSTEM**
FREQUENZSTEUERUNGSVERFAHREN UND FREQUENZSTEUERUNGSSYSTEM
PROCÉDÉ DE COMMANDE DE FRÉQUENCE ET SYSTÈME DE COMMANDE DE FRÉQUENCE

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Description

[0001] The present Invention relates to a frequency control method, a frequency control system, a frequency control device, or a frequency control program that reduces an influence of communication delay in controlling electric inputs or outputs of power sources so as to control a frequency of a grid.

[0002] There are many electricity transmission systems and distribution systems operating at a fixed frequency, for example, at 50 Hz or 60 Hz. Grid frequency control systems control resources such as power sources (generators) and energy storage resources.

[0003] In order to maintain grid frequency stability, grid operators send commands for controlling the amount of power withdrawn from the grid by loads and the amount of power injected to the grid by generators, storage, and renewable energy sources. The power sources and the energy storage resources control inputs or outputs of their power.

[0004] However, large delay occurs in transmission of command signals from a grid operator's computer to receivers. To overcome the delay, there is a system that creates, at a receiver side, a control signal having a grid frequency, instead of using commands sent from the grid operator (see reference JP 2005-20916 A, for example).

[0005] Reference US 2012/323389 (A1) discloses methods for controlling power realized by energy service equipment based on market data. An energy service unit may receive a request to regulate the grid frequency. The request may include an energy amount to charge and discharge, and the grid frequency. The energy service unit may stop frequency regulation based on a measurement by the energy service unit that the grid frequency is at or near the desired value.

[0006] The conventional systems, however, are not capable of overcoming problems caused by the delay in transmission from a grid operator's computer to receivers.

[0007] In view of the above, it is an object of the present invention to provide an improved frequency control method.

[0008] This is achieved by the features of independent claim 1. Preferred embodiments are the subject matter of the dependent claims.

[0009] According to the present invention, a frequency control method is provided, which includes a control prediction part for reducing an influence of communication delay and predicting a command for controlling electric inputs or outputs of systems connected to the grid more accurately.

[0010] These general and specific aspects may be implemented using a system, an apparatus, a method, an integrated circuit, a computer program, or a non-transitory computer-readable recording medium such as a CD-ROM, or any combination of systems, apparatuses, methods, integrated circuits, computer programs, or computer-readable recording media.

[Advantageous Effects of Invention]

[0011] According to the present invention, it is possible to reduce an influence of communication delay and to predict a command more accurately in controlling electric inputs or outputs of systems connected to a grid.

[Brief Description of Drawings]

[0012]

[Fig. 1] FIG. 1 is a diagram showing a system configuration according to an embodiment 1 of the present invention.
[Fig. 2] FIG. 2 is a diagram showing detailed configurations of a central control system and a local control system according to the embodiment 1 of the present invention.
[Fig. 3] FIG. 3 is a sequence diagram of an overall system.
[Fig. 4] FIG. 4 is a flowchart for a procedure of a prediction process algorithm in the central control system.
[Fig. 5A] FIG. 5A is a diagram showing an example of a model used for predicting a command using frequency measurements.
[Fig. 5B] FIG. 5B is a diagram showing an example of a model used for predicting a command using frequency measurements.
[Fig. 6] FIG. 6 is a diagram showing examples of a command, a delayed command, and a predicted command as a function of time.
[Fig. 7] FIG. 7 is a diagram showing detailed configurations of a central control system and a local control system according to an embodiment 2 of the present invention.
[Fig. 8] FIG. 8 is a flowchart for a procedure of a prediction process algorithm in the central control system according to the embodiment 2.
[Fig. 9] FIG. 9 is a diagram showing detailed configurations of a central control system and a local control system according to an embodiment 3 of the present invention.
[Fig. 10] FIG. 10 is a flowchart for a procedure of a prediction process algorithm in the central control system

according to the embodiment 3.

[Fig. 11] FIG. 11 is a diagram showing detailed configurations of a central control system and a local control system according to the embodiment 1, option 1, of the present invention.

[Fig. 12] FIG. 12 is a sequence diagram according to the embodiment 1, the option 1 of the present invention.

[Description of Embodiments]

[0013] The present invention is a frequency control method for use in a frequency control system including: a server that receives, from a power system operator, a power command for controlling a frequency of a power grid within a predetermined frequency; at least one distributed energy resource; and a local controller connected to the server through a communication network and to the at least one distributed energy resource. The frequency control method includes: receiving the power command from the power system operator; obtaining a frequency measurement of the power grid; predicting a next power command using the frequency measurement, before the next power command is received from the power system operator; and controlling an input or output of the at least one distributed power energy resource using the predicted next power command, before the next power command is received from the power system operator.

[0014] For example, the frequency control method may include: calculating communication delay time in the communication network; and controlling the input or output of the at least one distributed power energy resource using the predicted next power command, based on the communication delay time.

[0015] This reduces an influence of the communication delay, allowing responses of the distributed energy resources to be matched more closely to the command sent from the power system operator. The responses of the distributed energy resources can be matched more closely to the command sent from the power system operator, improving controllability and stability of the grid frequency.

[0016] For example, a difference between a timing at which the power system operator sends the power command and a timing at which the input or output of the at least one distributed power energy resource changes after the predicted next power command is received may be less than a predetermined time.

[0017] This reduces time from when the command is sent by the power system operator to when the input or output of the distributed energy resource is changed, thereby improving the stability of the frequency of the power grid.

[0018] For example, the frequency control method may predict the next power command using the frequency measurement and a relationship between the frequency measurement and the power command which are in a memory.

[0019] This enables the system to predict the command more accurately.

[0020] For example, the frequency control method may predict the next power command using the frequency measurement, a past received power command, and a model indicating a relationship between the frequency measurement and the power command to be received.

[0021] This allows the prediction of the command to be more accurate.

[0022] For example, the model may be a regression model.

[0023] This allows the prediction of the command to be more accurate. In addition, the model is so simple and fast for computation.

[0024] For example, the frequency control method may include: controlling the input or output of the at least one distributed power energy resource using the power command to be received when the communication delay time is less than a predetermined value, and controlling the input or output of the at least one distributed power energy resource using the predicted next power command when the communication delay time is greater than the predetermined value.

[0025] Accordingly, it is determined whether or not a negative effect of the transmission delay is large, reducing the influence of a prediction error especially in a small communication delay. Therefore, the input or output of the distributed energy resources can follow the command sent by the power system operator more accurately.

[0026] For example, the frequency control method may include: calculating a prediction error; controlling the input or output of the at least one distributed power energy resource using the power command to be received when the prediction error is greater than a predetermined value; and controlling the input or output of the at least one distributed power energy resource using the predicted next power command when the prediction error is less than the predetermined value.

[0027] Accordingly, it is determined whether or not a negative effect of the transmission delay is large, reducing the influence of the prediction error especially in a large prediction error. Therefore, the input or output of the distributed energy resources can follow the command sent by the power system operator more accurately.

[0028] For example, the frequency control method may include: calculating a communication state; controlling the input or output of the at least one distributed power energy resource using the frequency measurement and the power command to be received when the communication state is normal; and controlling the input or output of the at least one distributed power energy resource using the frequency measurement when the communication state is abnormal or disconnected.

[0029] Accordingly, the previously-received power command for making the prediction is used, improving accuracy of the command prediction during the communication network being up. Accordingly, the prediction process can continue

even when the network is down, by making the prediction based only on frequency measurements. In this method, predictions based only on frequency measurements is used, allowing the frequency regulation control to still continue even when problems occur in the network communication. In addition, the frequency regulation control is still accurate while the network communication is up.

[0030] For example, the frequency control method may be executed in the server by the server sending the power command to the local controller.

[0031] For example, the frequency control method may be executed in the local controller.

[0032] For example, a program is for use in a frequency control system including: a server that receives, from a power system operator, a power command for controlling a frequency of a power grid within a predetermined frequency; at least one distributed energy resource; and a local controller connected to the server through a communication network and to the at least one distributed energy resource. The program may cause the frequency control system to execute: receiving the power command from the power system operator; obtaining a frequency measurement of the power grid; predicting a next power command using the frequency measurement, before the next power command is received from the power system operator; and controlling an input or output of the at least one distributed power energy resource using the predicted next power command, before the next power command is received from the power system operator.

[0033] For example, a frequency control system includes: a server that receives, from a power system operator, a power command for controlling a frequency of a power grid within a predetermined frequency; at least one distributed energy resource; and a local controller connected to the server through a communication network and to the at least one distributed energy resource. The frequency control system may executes: receiving the power command from the power system operator; obtaining a frequency measurement of the power grid; predicting a next power command using the frequency measurement, before the next power command is received from the power system operator; and controlling an input or output of the at least one distributed power energy resource using the predicted next power command, before the next power command is received from the power system operator.

[0034] For example, a server is for use in a frequency control system including: the server that receives, from a power system operator, a power command for controlling a frequency of a power grid within a predetermined frequency; at least one distributed energy resource; and a local controller connected to the server through a communication network and to the at least one distributed energy resource. The server may include a controller that controls an input or output of the at least one distributed power energy resource. The controller may receive the power command from the power system operator; obtain a frequency measurement of the power grid; predict a next power command using the frequency measurement, before the next power command is received from the power system operator; and control the input or output of the at least one distributed power energy resource using the predicted next power command, before the next power command is received from the power system operator.

[0035] For example, a local controller is for use in a frequency control system including: a server that receives, from a power system operator, a power command for controlling a frequency of a power grid within a predetermined frequency; at least one distributed energy resource; and the local controller connected to the server through a communication network and to the at least one distributed energy resource. The local controller may include a controller that controls an input or output of the at least one distributed power energy resource. The controller may receive the power command from the power system operator; obtain a frequency measurement of the power grid; predict a next power command using the frequency measurement, before the next power command is received from the power system operator; and control the input or output of the at least one distributed power energy resource using the predicted next power command, before the next power command is received from the power system operator.

[0036] These general and specific aspects may be implemented using a system, an apparatus, a method, an integrated circuit, a computer program, or a non-transitory computer-readable recording medium such as a CD-ROM, or any combination of systems, apparatuses, methods, integrated circuits, computer programs, or computer-readable recording media.

[0037] Hereinafter, preferred embodiments of the present invention will be described with reference to the drawings. Each of the exemplary embodiments described below shows a general or specific example. The numerical values, shapes, materials, structural elements, the arrangement and connection of the structural elements, steps, the processing order of the steps etc. shown in the following exemplary embodiments are mere examples, and therefore do not limit the scope of the appended claims and their equivalents. Therefore, among the structural elements in the following exemplary embodiments, structural elements not recited in any one of the independent claims are described as arbitrary structural elements.

(Embodiment 1)

[0038] FIG. 1 shows an overview of a system configuration according to an embodiment 1 of the present invention.

[0039] As shown in FIG. 1, a system according to the embodiment 1 of the present invention includes a power system operator 101, a central control system 102, a frequency sensor 103, a local control system 104, a grid-tie inverter 105,

a controllable energy resource 106, and a power grid 107. The central control system 102 may have a frequency sensor 103. The system may have some local control systems 104. The power system operator 101 is connected to the central control system 102 with a single-purpose communication line through a communication medium which is typically a SCADA system.

[0040] The central control system 102 is connected to the local control system 104 through a communication medium. In the embodiment 1, the communication medium is a switched network between Ethernet (registered trademark) and wireless networks, and may be used for multiple purposes aside from sending control signals. This communication medium causes delay which occurs when the local control system 104 receives information transmitted by the central control system 102. The central control system 102 is connected to the frequency sensor 103 which provides frequency measurements through a communication interface. The frequency sensor 103 is a power meter, a power analyzer, or the like. Each of the central control system 102, the local control system 104, the grid-tie inverter 105 and the controllable energy resource 106 may include the frequency sensor 103.

[0041] The local control system 104 is connected to the grid-tie inverter 105, and can communicate with a controller of the grid-tie inverter 105.

[0042] The grid-tie inverter 105 is connected to the controllable energy resource 106 and to the power grid 107 through wires through which electric power is transmitted.

[0043] The controllable energy resource 106 may be an energy storage resource, load resource, or generation resource. In a case when the controllable energy resource 106 is the energy storage resource, the energy storage resource may be a storage battery or a plurality of storage batteries. A type of the storage battery may be a lithium-ion. The energy storage resource may also be pumped-hydro, compressed-air, flywheels, or capacitors. The controllable energy resource 106 may Include the local control system 104 and the grid-tie inverter 105.

[0044] A normal operation of the overall system is described.

[0045] In the normal operation, the power system operator 101 sends commands to cause the controllable energy resource 106 to raise or lower its power output to the grid 107 or power input from the grid 107. The commands are sent at a fixed period. The central control system 102 receives the commands. The central control system 102 computes prediction of a next command by calculating the commands from the power system operator 101 and the frequency measurements from the frequency sensor 103. The central control system 102 sends the predicted command to the local control system 104 earlier than the command sent from the power system operator 101 is received at the local control system 104. In other words, the predicted command is sent early. This will be described in more detail later.

[0046] Upon receiving the predicted command, the local control system 104 transmits the received command to the grid-tie inverter 105. The grid-tie inverter 105 adjusts power of the controllable energy resource 106 in response to the command. Accordingly, the power is injected to or drawn from the power grid 107.

[0047] If the central control system 102 is connected to more than one local control systems 104, the central control system 102 calculates a prediction of the next command, and subsequently calculates distribution of the commands to each of the local control systems 104. The distribution of the predicted command allows the desired input or output of an aggregate system to be divided among the controllable energy resources 106, according to the controllable energy resources 106 information such as capacity, max charge/discharge rate, or state of charge.

[0048] FIG. 2 is a detailed diagram showing configurations of the central control system 102 and the local control system 104 which are described with reference to FIG. 1.

[0049] The central control system 102 includes a command receiver 110, a frequency measurement receiver 111, a command predictor 112, a send time predictor 113, and a command sender 114.

[0050] The command receiver 110 receives commands sent by the power system operator 101.

[0051] The frequency measurement receiver 111 receives frequency measurements from the frequency sensor 103.

[0052] The command predictor 112 calculates predictions of a command to be received next, using combination of frequency measurements and past received commands, or frequency measurements only.

[0053] The send time predictor 113 decides an optimal timing to send the predicted command. For example, the send time predictor 113 decides when an influence of the delay is minimized in transmission of the command over the communication medium to the local control system 104.

[0054] The command sender 114 sends the predicted command to the local control system 104 at the timing decided by the send time predictor 113.

[0055] The command receiver 110, the frequency measurement receiver 111, and the command sender 114 may be any combination of devices such as ethernet (registered trademark) network interface cards or modems.

[0056] The local control system 104 includes a command receiver 115 and a local controller 116. The command receiver 115 receives the commands sent from the central control system 102. The local controller 116 sends appropriate commands to the grid-tie inverter 105.

[0057] A sequence diagram of an overall system is shown in FIG. 3.

[0058] The sequence of a method is described as an interaction of three actors: the power system operator 101, the central control system 102, and the local control system 104.

[0059] The power system operator 101 periodically sends commands to the central control system 102 in a fixed period (S120, S122).

[0060] At the same time, the prediction process is executed in the command predictor 112. For example, when the command receiver 110 receives an nth command sent from the power system operator 101, the command predictor 112 calculates the prediction for an n+1th command that is expected to be received from the power system operator 101. This prediction of the n+1th command is sent out of the command sender 114 to the command receiver 115 earlier than the command receiver 115 receives the actual n+1th command, in consideration of the delay in transmission between the central control system 102 and the local control system 104 (S121). For example, a time error between the n+1th command received and the actual n+1th command is less than 0.1 msec. Typical delay times are in the range of 0.1 msec to 1s. The amount of the delay time varies depending on the number of networking hops, distance, and traffic of the network between the central control system 102 and the local control system 104.

[0061] The command receiver 115 receives the predicted n+1th command, and the local controller 116 controls an input or output of the controllable energy resource 106 (S123).

[0062] This reduces the influence of the communication delay, thereby enabling responses of the distributed energy resources to be matched more closely to the commands sent from the power system operator 101.

[0063] A procedure of a prediction process algorithm executed in the central control system 102 will be described in detail with reference to a flowchart shown in FIG. 4.

[0064] First, the command receiver 110 receives an nth command (S130). After the nth command is received, the frequency measurement receiver 111 obtains a frequency measurement from a frequency measurement source as shown in FIG. 1 (S131). Then, using the received command and a frequency measurement, the command predictor 112 calculates a prediction of an n+1th command, i.e., the next command expected to be received (S132). The send time predictor 113 decides time instant at which the prediction of the n+1th command is sent to the local control system 104 (S133). This subprocess can proceed in parallel with the command prediction process. The command sender 114 waits by the time to send the predicted command (S134), and finally sends the predicted command to the local control system 104 (S135).

[0065] The entire process is repeated again to allow the n+1th command to be received, and to also allow an n+2th command to be predicted and sent (S136).

[0066] An algorithm for predicting the command (S132) and an algorithm for deciding when the predicted command is sent (S133) are described in further detail below.

[0067] The calculation of the predicted command is performed through a model. In a simple example, the prediction of the n+1th command is calculated as a linear combination of the received nth command (C_n), a measured frequency (f_n), and offset (d).

[Expression 1]

$$c_{n+1,predict} = ac_n + bf_n + d \ ,$$

[0068] Here, a, b, and d are model parameters. It is necessary for the model parameters to be set before they are used for prediction. The parameters undergo a process of offline model fitting using collected past command data and past frequency measurements, and subsequently are initialized and set in a memory before the prediction process begins. The parameters are also updated via online periodically, by periodically re-fitting the model, or through an adaptive algorithm continuously.

[0069] For the fitting algorithm, a linear regression may be used.

[0070] It should be noted that the prediction of the n+1th command can be calculated without using the nth command (in other words, using the frequency measurements only). Alternatively, the prediction of the n+1th command can be calculated using the frequency measurement, received nth command, and one or more of past frequency measurements or past received commands. With this, improvement in the prediction accuracy is also expected. Several other variations of the prediction model include the following.

[0071] Using past frequency measurements and past commands, the prediction model is expressed as follows.

[Expression 2]

$$c_{n+1,predict} = a_0 c_n + a_1 c_{n-1} + \ldots + a_N c_{n-N} + b_0 f_n + b_1 f_{n-1} + \ldots + b_M f_{n-M} + e$$

[0072] Using frequency measurements only, the prediction model is expressed as follows (this model is shown in FIGS. 5A and 5B).

[Expression 3]

$$c_{n+1,predict} = bf_n + d$$

[0073] Using a filter of past frequency measurements, the prediction model is expressed as follows:

[Expression 4]

$$c_{n+1,predict} = a_0 c_{n,predict} + a_1 c_{n-1,predict} + \ldots + a_N c_{n-N,predict} + b_0 f_n + b_1 f_{n-1} + \ldots + b_M f_{n-M}$$

[0074] Using a filter of past frequency measurements and past commands, the prediction model is expressed as follows:

[Expression 5]

$$c_{n+1,predict} = a_0 c_{n,predict} + a_1 c_{n-1,predict} + \ldots + a_N c_{n-N,predict} + d_0 c_n + d_1 c_{n-1} + \ldots + d_N c_{n-N} + b_0 f_n + b_1 f_{n-1} + \ldots + b_M f_{n-M}$$

[0075] It should be noted that values of parameters a, b, d, e, and so on after fitting are not necessarily the same among the models above.

[0076] An algorithm for deciding when the command is sent is described below.

[0077] First, an amount of delay in transmitting a command from the central control system 102 to the local control system 104 is estimated. For example, the delay is estimated by sending a ping, waiting until a reply to the ping is received, measuring time difference between the sending of the ping and the receiving of the reply, and dividing the measured time difference by two. An alternative way is to synchronize clocks of the central control system 102 and the local control system 104, and to include a time-stamp in a command when the command is sent to the local control system 104. The local control system 104 then compares the time-stamp in the command packet with a time point at which the local control system 104 has received the packet, so as to compute the delay as the difference. The delay information needs to be communicated back to the central control system 102.

[0078] When the delay is estimated, the send time predictor 113 decides the time instant to send the predicted command by the following equation.

[0079] Time at which the n+1th predicted command is sent = Time at which the nth command is received + a time period necessary for the power system operator to send commands - the estimated delay between the central control system 102 and the local control system 104.

[0080] Finally, an effect of the present invention will be described with reference to FIG. 6.

[0081] FIG. 6 shows an influence of the communication delay on the command signal, an example of the timing to send the predicted command, and an effect of sending the predicted command at the predetermined timing.

[0082] The first plot (a) is an example of a command sent from the power system operator 101. The graph plots the desired power input in or output from a resource relative to time. The command itself is sent periodically. Assuming that the transmission delay between the power system operator 101 and the central control system 102 is very small, a waveform of the desired input power or output power received at the central control system 102 is almost the same as that shown in the first plot (a).

[0083] The second plot (b) shows a waveform of commands when they are received. The commands are sent from the central control system 102 and are delayed due to the transmission delay In a communication medium. A horizontal arrow represents the delay time. If the local control system 104 follows this command signal, changes in the input power or output power, which occur in the local control system 104, are late from a point of view of the command signal sent by the power system operator 101.

[0084] Instead of simply sending the command received from the power system operator 101 to the local control system 104, the central control system 102 makes a prediction of a command signal to be received, and sends the predicted command signal earlier, in the embodiment 1 of the present invention.

[0085] The third plot (c) and the fourth plot (d) show waveforms of the predicted command signal that is the actual command signal temporally shifted from the predicted command signal by the amount of time equal to the estimated transmission delay. The predicted command is sent, and then arrives at the local control system 104 as if the central control system 102 has sent the actually received signal through a communication medium with less delay.

[0086] Comparing the signal in the first plot (a) with the signal in the fourth plot (d), they are not temporally shifted

earlier or later relative to each other.

[0087] In summary, the effect of the embodiment 1 of the present invention is that the response of the distributed energy resources can be matched more closely to the command sent from the power system operator 101, by reducing the influence of the communication delay.

[0088] As a result, the power system operator 101 can control the controllable energy resource 106 as intended.

(Embodiment 2)

[0089] An embodiment 2 of the present invention will be described below, with reference to FIGS. 7 and 8.

[0090] The embodiment 2 is similar to the embodiment 1, except that the embodiment 2 includes a command selector 202 having a function of deciding which one of predicted commands or actually received commands are sent. The command selector 202 sends the predicted command before the command from the power system operator 101 is received, waits until the command from the power system operator 101 is received, and then sends the received command.

[0091] The overall configuration of a system is the same as that of the embodiment 1, which is shown in FIG. 1. The local control system 104 is also the same as that of the embodiment 1, which is shown in FIG. 2. A detailed configuration of a central control system is shown in FIG. 7. A central control system 201 has the same parts as those in the embodiment 1, and thus such parts are not described here.

[0092] The central control system 201 includes the command selector 202, which is a unique part of the embodiment 2 of the present invention. The command selector 202 includes a prediction error memory 203, a communication delay memory 204, and a communication delay estimator 205. The command sender 114 sends a received or predicted command, which is selected by the command selector 202.

[0093] The prediction error memory 203 stores past records of prediction errors.

[0094] The communication delay memory 204 stores past transmission delay.

[0095] The communication delay estimator 205 estimates present transmission delay, which is a similar function as that of the aforementioned send time predictor 113.

[0096] The command selector 202 decides whether (i) sending the predicted command before the command is received, or (ii) waiting until the command is received by the central control controller and then sending the received command.

[0097] When the transmission delay is large, it may be optimal to send the prediction of a command early. However, when the transmission delay is small, it may not be necessary to send the prediction of the command early.

[0098] On the other hand, when the error in a prediction of the next command is large, it may be better to wait until the command is received and then send the received command. When the prediction error is small, it may be better to send the predicted command.

[0099] The command selector 202 estimates prediction errors using the prediction error memory 203 and estimates transmission delay using the communication delay memory 204 and the communication delay estimator 205. The command selector 202 decides a command to be sent based on the estimated prediction error and the estimated transmission delay (a method for deciding the command to be sent is described in more detail later).

[0100] FIG. 8 is a flowchart of an algorithm of the central control system 201.

[0101] When a process starts, the command selector 202 first decides whether or not to send the predicted command (S210). If the command selector 202 decides to send the predicted command (Yes at S210), the remainder of the flowchart is the same as those in the embodiment 1 (shown in FIG. 4). On the other hand, if the system decides not to send the predicted command (No at S210), the command selector 202 waits until the command receiver 110 receives an n+1th command (S211), and then the command sender 114 sends the received n+1th command to the local control system 104 immediately after the command receiver 110 receives the n+1th command (S212).

[0102] A method for deciding whether or not to send the predicted command is described below.

[0103] The command selector 202 decides which one of the predicted command and the received command should be sent for excellent overall system performance.

[0104] As an example of a criteria for the above, the command selector 202 selects whether or not to send the predicted command based on a threshold. For example, if the prediction error of the previous nth command is larger than a threshold value, the command selector 202 selects to send the received n+1th command instead of sending the predicted n+1th command. Alternatively, if the transmission delay of the previous command is larger than the threshold value, the command selector 202 selects to send the predicted n+1th command early instead of waiting to receive the n+1th command.

[0105] As another example of such criteria, the command selector 202 selects whether or not to send the predicted command or the received command based on which one of them contributes to the regulation service greater. In some regions, contribution to the regulation service depends on performance including several aspects such as command following accuracy.

[0106] Service providers may be penalized for inaccurate or delayed responses. In these regions, based on a calculation

method for an incentive applicable to the predetermined region, the command selector 202 can calculate the incentive to be hypothetically received in the case when a predicted response is sent with an estimated prediction error, and when the received command is sent with delay.

[0107] In summary, according to the embodiment 2 of the present invention, the local control system 104 can advantageously receive the predicted command or the actual command depending on the situation.

[0108] As a result, the power system operator 101 may control the controllable energy resource 106 as intended better.

(Embodiment 3)

[0109] An embodiment 3 of the present invention will be described below, with reference to FIGS. 9 and 10.

[0110] The embodiment 3 is similar to the embodiment 1, except that the embodiment 3 includes two command predictors based on models different from each other, and a model selector 303. A detailed configuration of a central control system is shown in FIG. 9. A central control system 301 has the same parts as those in the embodiment 1, and thus they are not described here.

[0111] The command predictor (model 1) 112 makes command predictions based both on received commands and received frequency measurements (prediction 1). On the other hand, a command predictor 302 (model 2) makes command predictions based only on the received frequency measurements (prediction 2). The model 1 and model 2 may be the same as the models described in the embodiment 1.

[0112] The model selector 303 selects which one of the command predictions (prediction 1 or prediction 2) is sent to the local control system 104 through the command sender 114. The model selector 303 includes a sensor 304. For example, the sensor 304 may be a method of sensing the condition of a communication network between the power system operator 101 and the central control system 301. If a state of the communication network is normal, the model selector 303 selects to use the prediction 1. If the communication with the power system operator 101 is abnormal or the connection is down, the command predictor 112 cannot receive commands from the power system operator 101 and cannot make the prediction 1, and therefore the model selector 303 selects to use the prediction 2.

[0113] FIG. 10 shows a flowchart of a prediction process in detail. When the prediction process starts, in the method, it is first decided whether communication network is up (S310). This is implemented by the sensor 304 shown in FIG. 9 through methods. For example, the communication network may be a TCP/IP network, and the sensor 304 may be a program used to judge a connection state based on how long ago the last received TCP acknowledge packet was.

[0114] If the model selector 303 decides that the network is down (No in S310), the command predictor 302 obtains the frequency measurement (S311), and calculates the prediction of an n+1th command with the model 2 (S312). If the model selector 303 decides that the network is up (Yes in S310), the command predictor 112 waits to receive an nth command (S130), obtains a frequency measurement (S131), and calculates the prediction of the n+1th command with the model 1 (S132). The remainder of the flowchart is the same as those in the embodiment 1 (shown in FIG. 4).

[0115] The model 1 has an advantage that its predictions are often more accurate, whereas the model 2 has an advantage that it can makes predictions without need for receiving the commands. This means that predictions can be made with the model 2 even when the communication network state is abnormal. Therefore, both the model 1 and the model 2, and a selector are advantageously used for implementing the method, thereby selecting the prediction 1 or the prediction 2 depending on the conditions of the communication network.

(Option 1)

[0116] Option 1 may be used together with any of the embodiments of the present invention. In the option 1, the method described in any of the embodiments is implemented on local control systems 402 of distributed energy resources, instead of on a central control system 401.

[0117] The overview of a system configuration according to the option 1 is shown in FIG. 11. This option of the embodiment 1 is the same as the embodiment 1 shown in FIG. 2, except that a prediction algorithm is used on the local control system 402 instead of the central control system 401.

[0118] The central control system 401 includes a command distribution 403. If there are more than one local control system 402, the command distribution 403 distributes received commands to the local control systems 402.

[0119] The local control system 402 includes the command receiver 115, the frequency measurement receiver 111, a command predictor 412, a command sender 404, and the send time predictor 113. The command receiver 115 and the frequency measurement receiver 111 are both connected to the command predictor 412, and the command sender 404 is connected to the command predictor 412 and the send time predictor 113. The local control system 402 has a configuration partially identical to that in the embodiment 1.

[0120] The command predictor 412 makes predictions of a command to be received next from the central control system 401. The command sender 404 sends the predicted commands to controllers of distributed energy resources. The predicted command is sent at an earlier time than the command is received by the central control system 401. More

precisely, the time at which the command is sent is decided by the send time predictor 113.

[0121] The controller of the distributed energy resource mentioned above may be a microcontroller that implements a method of controlling the power input or output of the grid-tie inverter 105 that connects the controllable energy resource 106 to the power grid 107. The controller of the distributed energy resource and the local control system 402, where the method of the present invention is implemented, may be on the same circuit board or different boards physically close to each other, and may be connected through serial or parallel end-to-end connections or buses. Such connection has low latency.

[0122] The effect of the option 1 is the same as those in any of the above embodiments: the influence of the communication delay is decreased. There is an additional advantage of the option 1: the prediction process is implemented on the local control system 402 side instead of the central control system 401 side, thereby reducing the time difference between the sampling of the frequency measurement and the arrival of the sent predicted command at the energy resource. This is because that the delay does not incur in transmitting the predicted command through the communication network.

[0123] The advantage of having less delay between the sampling of the frequency measurement and control action by the energy resource controller is that the system can respond faster to changes in the frequency. This makes the system more effective at controlling grid frequency fluctuations.

[0124] The detailed sequence of the method according to the option 1 is shown in FIG. 12.

[0125] The power system operator 101 sends commands at a fixed period of time (S120). The central control system 401 sends the commands to the local control system 402 as soon as the central control system 401 receives the commands. The time at which the commands arrive at the local control system 402 is delayed due to transmission delay in a communication medium between the central control system 401 and the local control system 402.

[0126] The prediction process is running on the local control system 402. For example, if the prediction process according to the embodiment 1 (shown in FIG. 4) is used, the prediction process running on the local control system 402 could be the same as those described in the embodiment 1 (S421). After the prediction, the local control system 402 waits by the time decided to send the predicted command, and then sends the predicted command to the grid-tie inverter 105 (S422). As shown in the sequence of FIG. 12, the prediction of a command n+1 is sent to the grid-tie inverter 105 earlier than the n+1th command is received by the central control system 401. The timing of sending the prediction of the command n+1 is decided so that the prediction arrives at the grid-tie inverter 105 at the same time as the command n+1 is received by the grid-tie inverter 105 in the case when no delay incurs in the communication between the central control system 401 and local control system 402.

[0127] This option 1 can be incorporated in the embodiment 1, the embodiment 2, and the embodiment 3.

[0128] Each of the structural elements in each of the above-described embodiments may be configured in the form of an exclusive hardware product, or may be realized by executing a software program suitable for the structural element. Each of the structural elements may be realized by means of a program executing unit, such as a CPU and a processor, reading and executing the software program recorded on a recording medium such as a hard disk or a semiconductor memory. Here, the software program for realizing the system, and the like according to each of the embodiments is a program described below

[0129] Specifically, the program causes a computer to execute a frequency control method for use in a frequency control system including: a server that receives, from a power system operator, a power command for controlling a frequency of a power grid within a predetermined frequency; at least one distributed energy resource; and a local controller connected to the server through a communication network and to the at least one distributed energy resource. The frequency control method includes: receiving the power command from the power system operator; obtaining a frequency measurement of the power grid; predicting a next power command using the frequency measurement, before the next power command is received from the power system operator; and controlling an input or output of the at least one distributed power energy resource using the predicted next power command, before the next power command is received from the power system operator.

[0130] Each of the components may be a circuit. These circuits, as a whole, may form a single circuit, or may independently be a single circuit. Each of the circuits may be a general circuit or a dedicated circuit.

[0131] Although frequency control methods according to one or more embodiments are described in accordance with the embodiments, the present invention is not limited to the embodiments. Forms obtained by various modifications to the exemplary embodiments that can be conceived by a person of skill in the art as well as forms realized by combining structural components in different exemplary embodiments, which are within the scope of the essence of the present disclosure may be included in one or more aspects.

[0132] For example, processes performed by a specified processing unit may be performed by another processing unit. In addition, the order of a plurality of processes may be changed, and a plurality of processes may be performed in parallel.

[Industrial Applicability]

[0133] The present invention is useful for frequency control in a power system.

[Reference Signs List]

[0134]

101:	Power system operator
102, 201, 301, 401:	Central control system
103:	Frequency sensor
104, 402:	Local control system
105:	Grid-tie inverter (Inverter)
106:	Controllable energy resource
107:	Electricity grid
110, 115:	Command receiver
111:	Frequency measurement receiver
112, 302, 412:	Command predictor
113:	Send time predictor
114, 404:	Command sender
116:	Local controller
202:	Command selector
203:	Prediction error memory
204:	Communication delay memory
205:	Communication delay estimator
303:	Model selector
304:	Sensor
403:	Command distribution

Claims

1. A frequency control method for use in a frequency control system including:

a server (102) adapted for successively receiving, from a power system operator (101), power commands for controlling a frequency of a power grid within a predetermined frequency, said power commands comprising a first power command and a second power command transmitted subsequently to the first power command;
at least one distributed energy resource (106); and
a local controller (104) connected to the server (102) through a communication network and to the at least one distributed energy resource (106),
the frequency control method comprising:

receiving (S130) the first power command from the power system operator (101);
obtaining (S131) a frequency measurement of the power grid; **characterized in** predicting (S132) the second power command using the frequency measurement, before the second power command is received from the power system operator (101); and controlling an input or output of the at least one distributed power energy resource (106) using the predicted power command, before the second power command is received from the power system operator (101).

2. The frequency control method according to claim 1, comprising:

calculating communication delay time in the communication network; and
controlling the input or output of the at least one distributed power energy resource (106) using the predicted power command, based on the communication delay time.

3. The frequency control method according to claim 2 comprising:

controlling the input or output of the at least one distributed power energy resource (106) using the second

power command to be received when the communication delay time is less than a predetermined value, and controlling the input or output of the at least one distributed power energy resource (106) using the predicted power command when the communication delay time is greater than the predetermined value.

4. The frequency control method according to any one of claims 1 to 3, wherein a difference between a timing at which the power system operator (101) sends the power command and a timing at which the input or output of the at least one distributed power energy resource (106) changes after the predicted power command is received is less than a predetermined time.

5. The frequency control method according to any one of claims 1 to 4, comprising:

predicting the second power command using the frequency measurement and a relationship between the frequency measurement and the first power command which are in a memory.

6. The frequency control method according to any one of claims 1 to 5, comprising predicting the second power command using the frequency measurement, a previously received power command, and a model indicating a relationship between the frequency measurement and the power command to be received.

7. The frequency control method according to claim 6, wherein the model is a regression model.

8. The frequency control method according to any one of claims 1 to 7, comprising:

calculating a prediction error;
controlling the input or output of the at least one distributed power energy resource (106) using the power command to be received when the prediction error is greater than a predetermined value; and
controlling the input or output of the at least one distributed power energy resource (106) using the predicted power command when the prediction error is less than the predetermined value.

9. The frequency control method according to any one of claims 1 to 8, comprising:

calculating a communication state; and
controlling the input or output of the at least one distributed power energy resource (106) using the frequency measurement when the communication state is abnormal or disconnected.

10. The frequency control method according to any one of claims 1 to 9, the method being executed in the server (102) by the server (102) sending the power command to the local controller (104).

11. The frequency control method according to any one of claims 1 to 10, the method being executed in the local controller (104).

12. A program for use in a frequency control system, said frequency control system including:

a server (102) adapted for successively receiving, from a power system operator (101), power commands for controlling a frequency of a power grid within a predetermined frequency;
at least one distributed energy resource (106); and
a local controller (104) connected to the server (102) through a communication network and to the at least one distributed energy resource (106),
said program being adapted for causing the frequency control system to execute all steps of a method according to any of claims 1 to 11.

13. A frequency control system comprising:

a server (102) that receives, from a power system operator (101), a power command for controlling a frequency of a power grid within a predetermined frequency, said power commands comprising a first power command and a second power command transmitted subsequently to the first power command;
at least one distributed energy resource (106); and
a local controller (104) connected to the server (102) through a communication network and to the at least one distributed energy resource (106),

the frequency control system adapted for executing all steps of a method according to any of claims 1 to 11.

14. A server (102) for use in a frequency control system, said frequency control system including:

the server (102) that receives, from a power system operator (101), a power command for controlling a frequency of a power grid within a predetermined frequency;
at least one distributed energy resource (106); and
a local controller (104) connected to the server (102) through a communication network and to the at least one distributed energy resource (106),
said server (102) comprising
a controller for controlling an input or output of the at least one distributed power energy resource (106),
wherein the controller is adapted for performing all steps of a method according to any of claims 1 to 11.

15. A local controller (104) for use in a frequency control system, said frequency control system including:

a server (102) that receives, from a power system operator (101), a power command for controlling a frequency of a power grid within a predetermined frequency;
at least one distributed energy resource (106); and
the local controller (104) connected to the server (102) through a communication network and to the at least one distributed energy resource (106),
said local controller (104) comprising
a controller that controls an input or output of the at least one distributed power energy resource (106),
wherein the controller is adapted for performing all steps of a method according to any of claims 1 to 11.

Patentansprüche

1. Frequenzsteuerungsverfahren zur Anwendung in einem Frequenzsteuerungssystem, einschließend:

einen Server (102), daran angepasst, von einem Stromsystembetreiber (101) nacheinander Strombefehle zur Steuerung einer Frequenz eines Stromnetzes innerhalb einer vorgegebenen Frequenz, zu empfangen, wobei die Strombefehle einen ersten Strombefehl und einen zweiten Strombefehl, der anschließend zu dem ersten Strombefehl übertragen wird; umfassen;
mindestens einen dezentralisierten (distributed) Energieträger (106); und
eine lokale Steuerung (104), die über ein Kommunikationsnetzwerk mit dem Server (102) und mit dem mindestens einen dezentralisierten Energieträger (106) verbunden ist,
wobei das Frequenzsteuerungsverfahren umfasst:

Empfangen (S310) des ersten Strombefehls von dem Stromsystembetreiber (101);
Erhalten (S131) einer Frequenzmessung des Stromnetzes;
gekennzeichnet, durch
Vorhersagen (S132) des zweiten Strombefehls unter Anwendung der Frequenzmessung, bevor der zweite Strombefehl von dem Stromsystembetreiber (101) empfangen wird; und
Steuerung einer Eingabeleistung oder Ausgabeleistung des mindestens einen dezentralisierten Stromenergieträgers (106) unter Anwendung des vorhergesagten Strombefehls, bevor der zweite Strombefehl von dem Stromsystembetreiber (101) empfangen wird.

2. Frequenzsteuerungsverfahren nach Anspruch 1, umfassend:

Berechnen der Kommunikationszeitverzögerung in dem Kommunikationsnetzwerk, und
Steuerung der Eingabeleistung oder Ausgabeleistung des mindestens einen dezentralisierten Stromenergieträgers (106) unter Anwendung des vorhergesagten Strombefehls, basierend auf der Kommunikationszeitverzögerung.

3. Frequenzsteuerungsverfahren nach Anspruch 2, umfassend:

Steuerung der Eingabeleistung oder Ausgabeleistung des mindestens einen dezentralisierten Stromenergieträgers (106) unter Anwendung des zu empfangenden zweiten Strombefehls, wenn die Kommunikationszeit-

verzögerung kleiner als ein vorgegebener Wert ist, und
Steuerung der Eingabeleistung oder Ausgabeleistung des mindestens einen dezentralisierten Stromenergieträgers (106) unter Anwendung des vorhergesagten Strombefehls, wenn die Kommunikationszeitverzögerung größer als der vorgegebene Wert ist.

4. Frequenzsteuerungsverfahren nach einem der Ansprüche 1 bis 3, wobei eine Differenz zwischen einem Zeitpunkt, an dem der Stromsystembetreiber (101) den Strombefehl versendet, und einem Zeitpunkt, an dem die Eingabeleistung oder Ausgabeleistung des mindestens einen dezentralisierten Stromenergieträgers (106) sich ändert, nachdem der vorhergesagte Strombefehl erhalten wird, kleiner als eine vorgegebene Zeitdauer ist.

5. Frequenzsteuerungsverfahren nach einem der Ansprüche 1 bis 4, umfassend:

Vorhersage des zweiten Strombefehls unter Anwendung der Frequenzmessung und einer Beziehung zwischen der Frequenzmessung und dem ersten Strombefehl, die gespeichert sind.

6. Frequenzsteuerungsverfahren nach einem der Ansprüche 1 bis 5, umfassend das Vorhersagen des zweiten Strombefehls unter Anwendung der Frequenzmessung, eines zuvor empfangenen Strombefehls, und eines Modells, das eine Beziehung zwischen der Frequenzmessung und dem zu empfangenden Strombefehl angibt.

7. Frequenzsteuerungsverfahren nach Anspruch 6, wobei das Modell ein Regressionsmodell ist.

8. Frequenzsteuerungsverfahren nach einem der Ansprüche 1 bis 7, umfassend:

Berechnung eines Vorhersagefehlers;
Steuerung der Eingabeleistung oder Ausgabeleistung des mindestens einen dezentralisierten Stromenergieträgers (106) unter Anwendung des zu empfangenden Strombefehls, wenn der Vorhersagefehler größer als ein vorgegebener Wert ist; und Steuerung der Eingabeleistung oder Ausgabeleistung des mindestens einen dezentralisierten Stromenergieträgers (106) unter Anwendung des vorhergesagten Strombefehls, wenn der Vorhersagefehler kleiner als der vorgegebene Wert ist.

9. Frequenzsteuerungsverfahren nach einem der Ansprüche 1 bis 8, umfassend:

Berechnung eines Kommunikationszustands; und
Steuerung der Eingabeleistung oder Ausgabeleistung des mindestens einen dezentralisierten Stromenergieträgers (106) unter Anwendung der Frequenzmessung, wenn der Kommunikationszustand fehlerhaft oder unterbrochen ist.

10. Frequenzsteuerungsverfahren nach einem der Ansprüche 1 bis 9, wobei das Verfahren in dem Server (102) durch den Server (102) ausgeführt wird, der den Strombefehl an die lokale Steuerung (104) sendet.

11. Frequenzsteuerungsverfahren nach einem der Ansprüche 1 bis 10, wobei das Verfahren in der lokalen Steuerung (104) ausgeführt wird.

12. Programm zur Verwendung in einem Frequenzsteuerungssystem, wobei das Frequenzsteuerungssystem einschließt:

einen Server (102), daran angepasst, von einem Stromsystembetreiber (101) Strombefehle zur Steuerung einer Frequenz eines Stromnetzes innerhalb einer vorgegebenen Frequenz aufeinanderfolgend zu empfangen;
mindestens einen dezentralisierten Energieträger (106); und
eine lokale Steuerung (104), die über ein Kommunikationsnetzwerk mit dem Server (102) und mit dem mindestens einen dezentralisierten Energieträger (106) verbunden ist,
wobei das Programm daran angepasst ist, das Frequenzsteuerungssystem zu veranlassen, alle Schritte eines Verfahrens nach einem der Ansprüche 1 bis 11 durchzuführen.

13. Frequenzsteuerungssystem, umfassend:

einen Server (102), der von einem Stromsystembetreiber (101) einen Strombefehl zur Steuerung einer Frequenz eines Stromnetzes innerhalb einer vorgegebenen Frequenz empfängt, wobei die Strombefehle einen ersten

Strombefehl und einen zweiten Strombefehl, der anschließend zu dem ersten Strombefehl übertragen wird, umfassen;
mindestens eine dezentralisierte Energiequelle (106); und
eine lokale Steuerung (104), die über ein Kommunikationsnetzwerk mit dem Server (102) und mit dem mindestens einen dezentralisierten Energieträger (106) verbunden ist,
wobei das Frequenzsteuersystem an die Ausführung aller Schritte eines Verfahrens nach einem der Ansprüche 1 bis 11 angepasst ist.

14. Server (102) zur Verwendung in einem Frequenzsteuerungssystem, wobei das Frequenzsteuerungssystem einschließt:

den Server (102), der von einem Stromsystembetreiber (101) einen Strombefehl zur Steuerung einer Frequenz eines Stromnetzes innerhalb einer vorgegebenen Frequenz empfängt;
mindestens einen dezentralen Energieträger (106); und
eine lokale Steuerung (104), die über ein Kommunikationsnetzwerk mit dem Server (102) und mit dem mindestens einen dezentralisierten Energieträger (106) verbunden ist,
wobei der Server (102) umfasst:

eine Steuerung zum Steuern der Eingabeleistung oder der Ausgabeleistung des mindestens einen dezentralisierten Energieträgers (106),
wobei die Steuerung daran angepasst ist, alle Schritte eines Verfahrens nach einem der Ansprüche 1 bis 11 durchzuführen.

15. Lokale Steuerung (104) zur Verwendung in einem Frequenzsteuerungssystem, wobei das Frequenzsteuerungssystem einschließt:

einen Server (102), der von einem Stromsystembetreiber (101) einen Strombefehl zur Steuerung einer Frequenz eines Stromnetzes innerhalb einer vorgegebenen Frequenz empfängt;
den mindestens einen dezentralen Energieträger (106); und
die lokale Steuerung (104), die über ein Kommunikationsnetzwerk mit dem Server (102) und mit dem mindestens einen dezentralisierten Energieträger (106) verbunden ist,
wobei die lokale Steuerung (104) umfasst:

eine Steuerung, die die Eingabeleistung oder die Ausgabeleistung des mindestens einen dezentralisierten Energieträgers (106) steuert,
wobei die Steuerung daran angepasst ist, alle Schritte eines Verfahrens nach einem der Ansprüche 1 bis 11 durchzuführen.

Revendications

1. Procédé de commande de fréquence à utiliser dans un système de commande de fréquence incluant :

un serveur (102) conçu pour recevoir successivement, d'un opérateur de système de puissance (101), des commandes de puissance permettant de commander la fréquence d'un réseau électrique dans une fréquence prédéterminée, lesdites commandes de puissance comprenant une première commande de puissance et une seconde commande de puissance transmise à la suite de la première commande de puissance,
au moins une ressource d'énergie répartie (106), et
un contrôleur local (104) relié au serveur (112) par l'intermédiaire d'un réseau de communication et à la ou aux ressources d'énergie réparties (106),
le procédé de commande de fréquence comprenant :

la réception (S130) d'une première commande de puissance provenant de l'opérateur du système de puissance (101),
la récupération (S131) d'une mesure de fréquence du réseau électrique,
caractérisé par
la prédiction (S132) de la seconde commande de puissance en utilisant la mesure de fréquence avant que la seconde commande de puissance soit reçue de l'opérateur du système de puissance (101), et

la commande d'une entrée ou d'une sortie de la ou des ressources d'énergie réparties (106) en utilisant la commande de puissance prédite avant que la seconde commande de puissance soit reçue de l'opérateur du système de puissance (101).

2. Procédé de commande de fréquence selon la revendication 1, comprenant :

le calcul d'une durée de délai de communication dans le réseau de communication, et
la commande de l'entrée ou de la sortie de la ou des ressources d'énergie réparties (106) en utilisant la commande de puissance prédite sur la base de la durée de délai de communication.

3. Procédé de commande de fréquence selon la revendication 2, comprenant :

la commande de l'entrée ou de la sortie de la ou des ressources d'énergie réparties (106) en utilisant la seconde commande de puissance à recevoir lorsque la durée de délai de communication est inférieure à une valeur prédéterminée, et
la commande de l'entrée ou de la sortie de la ou des ressources d'énergie réparties (106) en utilisant la commande de puissance prédite lorsque la durée de délai de communication est supérieure à la valeur prédéterminée.

4. Procédé de commande de fréquence selon l'une quelconque des revendications 1 à 3, dans lequel la différence entre un séquencement avec lequel l'opérateur du système de puissance (101) envoie la commande de puissance et un séquencement avec lequel l'entrée ou la sortie de la ou des ressources d'énergie réparties (106) change après la réception de la commande de puissance prédite est inférieure à une durée prédéterminée.

5. Procédé de commande de fréquence selon l'une quelconque des revendications 1 à 4, comprenant :

la prédiction de la seconde commande de puissance en utilisant la mesure de fréquence et une relation entre la fréquence de mesure et la première commande de puissance qui se trouvent en mémoire.

6. Procédé de commande de fréquence selon l'une quelconque des revendications 1 à 5, comprenant la prédiction de la seconde commande de puissance en utilisant la mesure de fréquence, une commande de puissance précédemment reçue et un modèle indiquant une relation entre la mesure de fréquence et la commande de puissance à recevoir.

7. Procédé de commande de fréquence selon la revendication 6, dans lequel le modèle est un modèle de régression.

8. Procédé de commande de fréquence selon l'une quelconque des revendications 1 à 7, comprenant :

le calcul d'une erreur de prédiction,
la commande de l'entrée ou de la sortie de la ou des ressources d'énergie réparties (106) en utilisant la commande de puissance à recevoir lorsque l'erreur de prédiction est supérieure à une valeur prédéterminée, et
la commande de l'entrée ou de la sortie de la ou des ressources d'énergie réparties (106) en utilisant la commande de puissance prédite lorsque l'erreur de prédiction est inférieure à la valeur prédéterminée.

9. Procédé de commande de fréquence selon l'une quelconque des revendications 1 à 8, comprenant :

le calcul d'un état de communication, et
la commande de l'entrée ou de la sortie de la ou des ressources d'énergie réparties (106) en utilisant la mesure de fréquence lorsque l'état de communication est anormal ou déconnecté.

10. Procédé de commande de fréquence selon l'une quelconque des revendications 1 à 9, le procédé étant exécuté dans le serveur (102) par le serveur (112) qui envoie la commande de puissance au contrôleur local (104).

11. Procédé de commande de fréquence selon l'une quelconque des revendications 1 à 10, le procédé étant exécuté dans le contrôleur local (104).

12. Programme destiné à être utilisé dans un système de commande de fréquence, ledit système de commande de fréquence incluant :

un serveur (102) conçu pour recevoir successivement, d'un opérateur de système de puissance (101), des commandes de puissance permettant de commander la fréquence d'un réseau électrique dans une fréquence prédéterminée,
au moins une ressource d'énergie répartie (106), et
un contrôleur local (104) relié au serveur (102) par l'intermédiaire d'un réseau de communication et à la ou aux ressources d'énergie réparties (106),
ledit programme étant conçu pour amener le système de commande de fréquence à exécuter toutes les étapes d'un procédé conforme à l'une quelconque des revendications 1 à 11.

13. Système de commande de fréquence comprenant :

un serveur (102) qui reçoit, d'un opérateur de système de puissance (101), une commande de puissance permettant de commander la fréquence d'un réseau électrique dans une fréquence prédéterminée, lesdites commandes de puissance comprenant une première commande de puissance et une seconde commande de puissance transmise à la suite de la première commande de puissance,
au moins une ressource d'énergie répartie (106), et
un contrôleur local (104) relié au serveur (102) par l'intermédiaire d'un réseau de communication et à la ou aux ressources d'énergie réparties (106),
le système de commande de fréquence étant conçu pour exécuter toutes les étapes d'un procédé conforme à l'une quelconque des revendications 1 à 11.

14. Serveur (102) destiné à une utilisation dans un système de commande de fréquence, ledit système de commande de fréquence incluant :

le serveur (102) qui reçoit, d'un opérateur de système de puissance (101), une commande de puissance permettant de commander la fréquence d'un réseau électrique dans une fréquence prédéterminée,
au moins une ressource d'énergie répartie (106), et
un contrôleur local (104) relié au serveur (102) par l'intermédiaire d'un réseau de communication et à la ou aux ressources d'énergie réparties (106),
ledit serveur comprenant :

un contrôleur destiné à commander une entrée ou une sortie de la ou des ressources d'énergie réparties (106),
dans lequel le contrôleur est conçu pour effectuer toutes les étapes d'un procédé conforme à l'une quelconque des revendications 1 à 11.

15. Contrôleur local (104) destiné à une utilisation dans un système de commande de fréquence, ledit système de commande de fréquence incluant :

un serveur (102) qui reçoit, d'un opérateur de système de puissance (101), une commande de puissance permettant de commander la fréquence d'un réseau électrique dans une fréquence prédéterminée,
au moins une ressource d'énergie répartie (106), et
un contrôleur local (104) relié au serveur (102) par l'intermédiaire d'un réseau de communication et à la ou aux ressources d'énergie réparties (106),
ledit contrôleur local (104) comprenant :

un contrôleur qui commande une entrée ou une sortie de la ou des ressources d'énergie réparties (106),
le contrôleur étant conçu pour exécuter toutes les étapes d'un procédé conforme à l'une quelconque des revendications 1 à 11.

FIG. 1

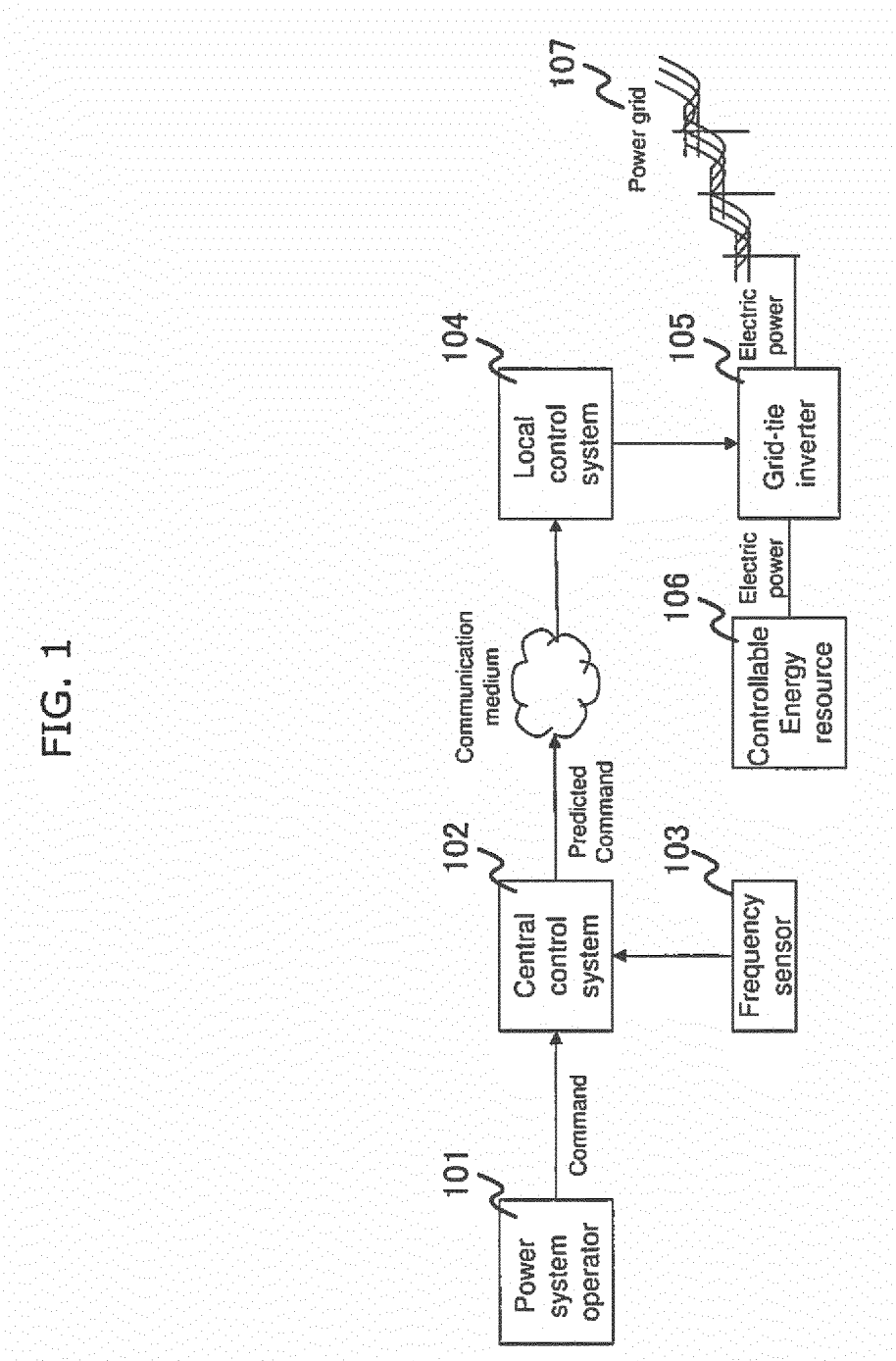

101
Power system operator
Command
102
Central control system
Predicted Command
103
Frequency sensor
Communication medium
104
Local control system
105
Grid-tie inverter
Electric power
106
Controllable Energy resource
Electric power
107
Power grid

FIG. 2

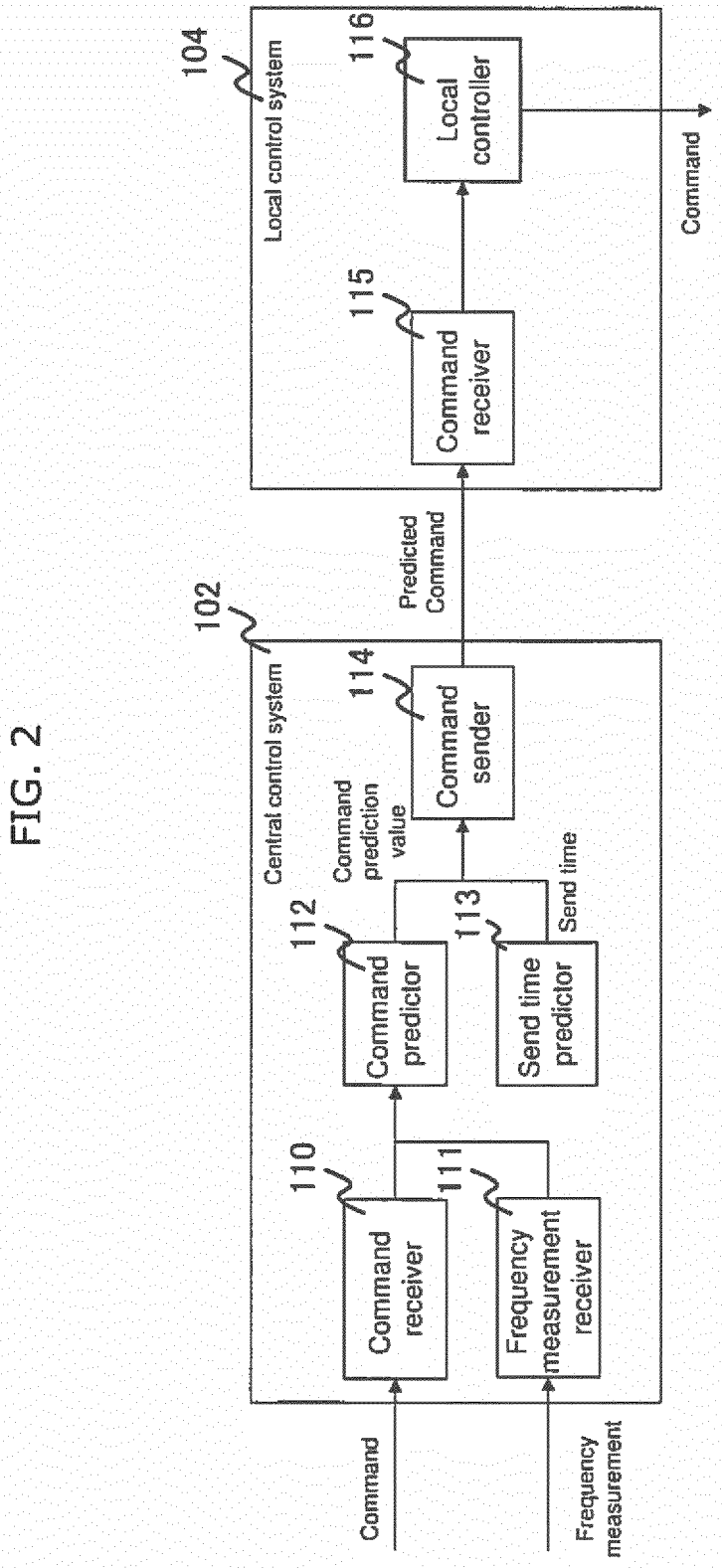

104
Local control system
116
Local controller
Command
115
Command receiver
Predicted Command
102
Central control system
114
Command sender
Command prediction value
112
Command predictor
113
Send time predictor
Send time
110
Command receiver
111
Frequency measurement receiver
Command
Frequency measurement

FIG. 3

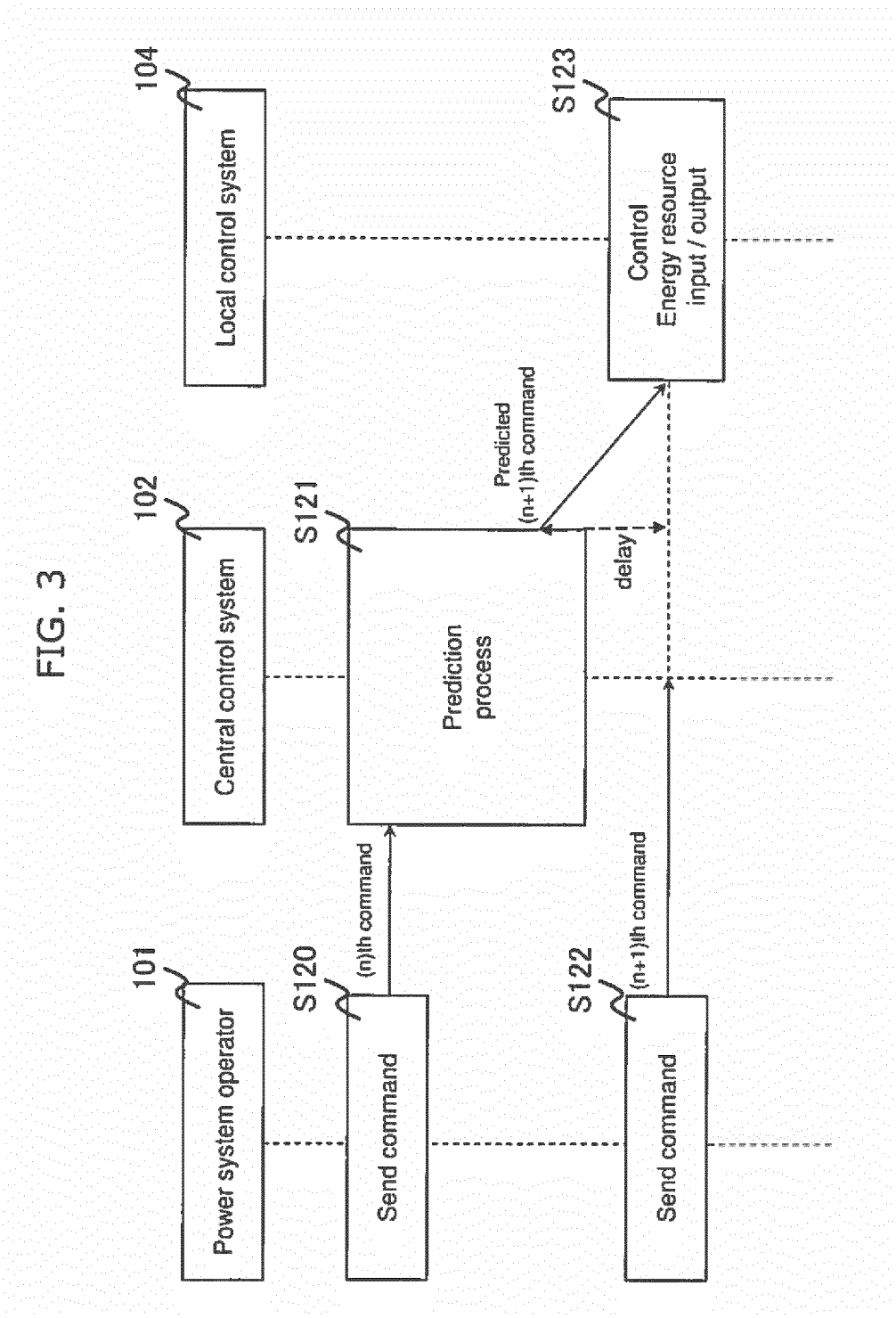

104
Local control system
S123
Control
Energy resource
input / output
Predicted
(n+1)th command
102
Central control system
S121
Prediction
process
delay
(n)th command
(n+1)th command
101
Power system operator
S120
Send command
S122
Send command

FIG. 4

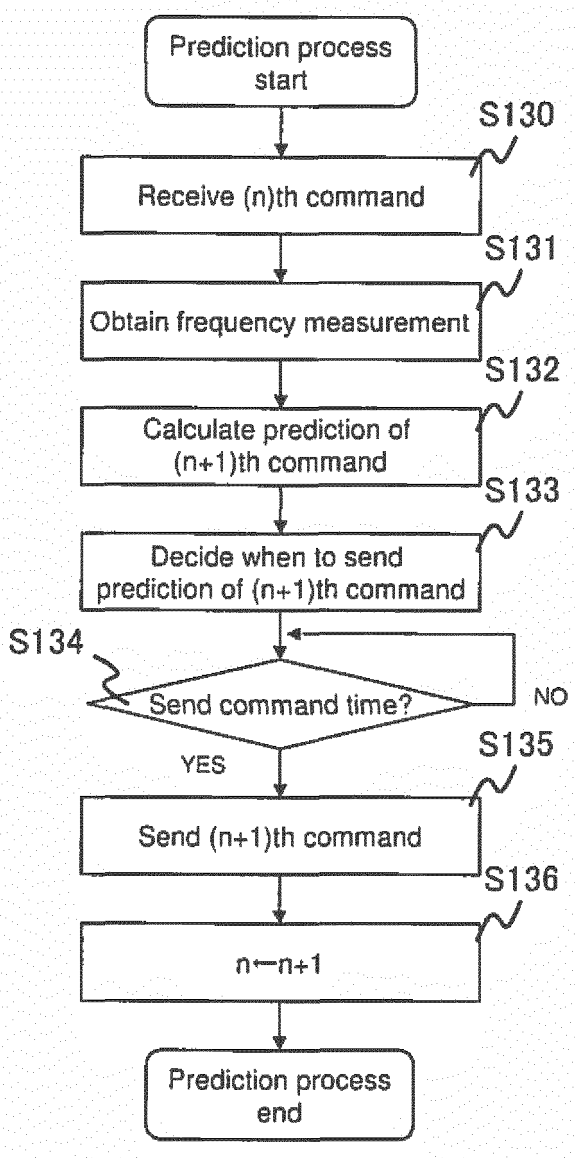

Prediction process start
S130
Receive (n)th command
S131
Obtain frequency measurement
S132
Calculate prediction of (n+1)th command
S133
Decide when to send prediction of (n+1)th command
S134
Send command time?
NO
YES
S135
Send (n+1)th command
S136
n←n+1
Prediction process end

FIG. 5A

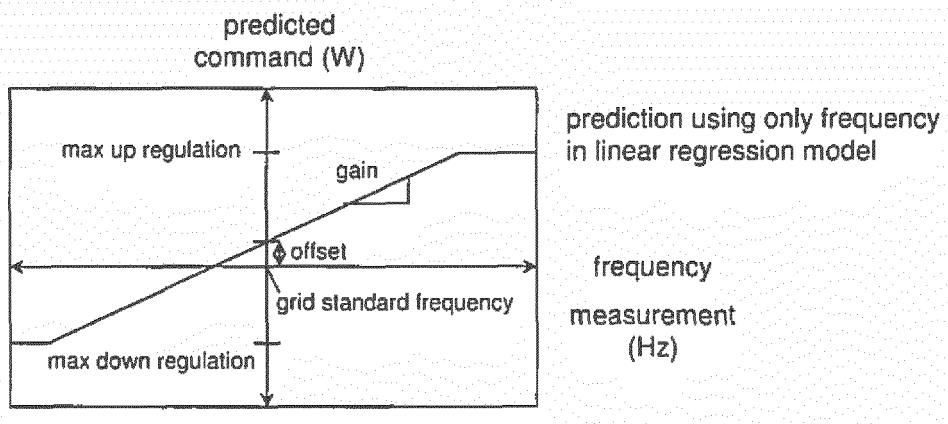

predicted
command (W)
max up regulation
gain
offset
grid standard frequency
max down regulation
prediction using only frequency
in linear regression model
frequency
measurement
(Hz)

FIG. 5B

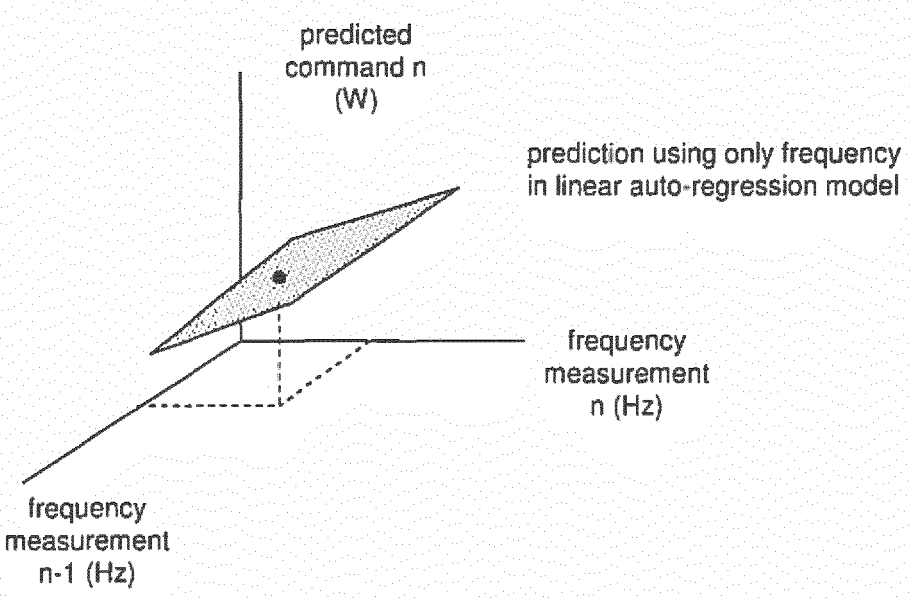

predicted
command n
(W)
prediction using only frequency
in linear auto-regression model
frequency
measurement
n (Hz)
frequency
measurement
n-1 (Hz)

FIG. 6

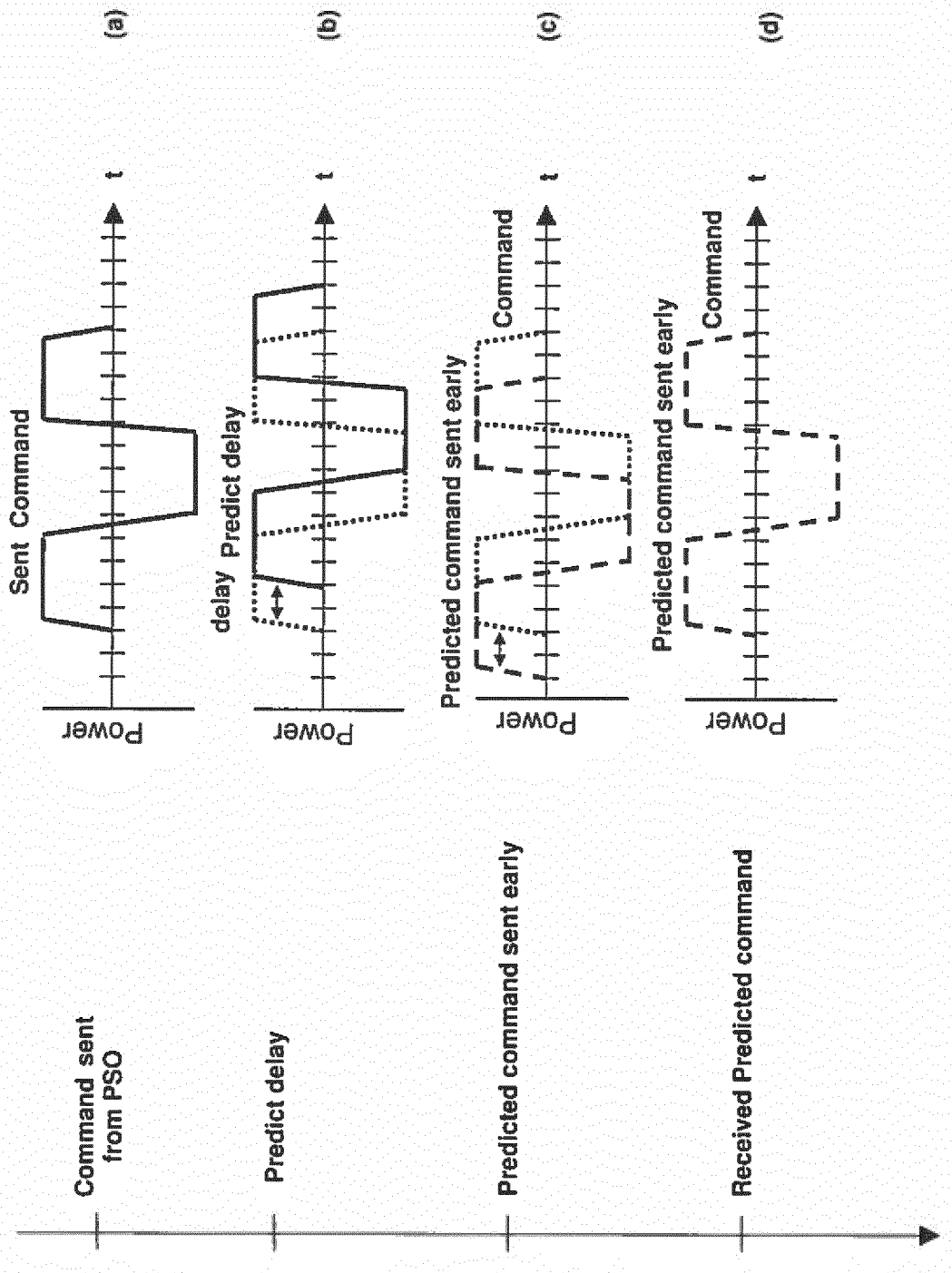

(a)
Sent Command
Power
t
(b)
delay
Predict delay
Power
t
(c)
Predicted command sent early
Command
Power
t
(d)
Predicted command sent early
Command
Power
t
Command sent from PSO
Predict delay
Predicted command sent early
Received Predicted command

FIG. 7

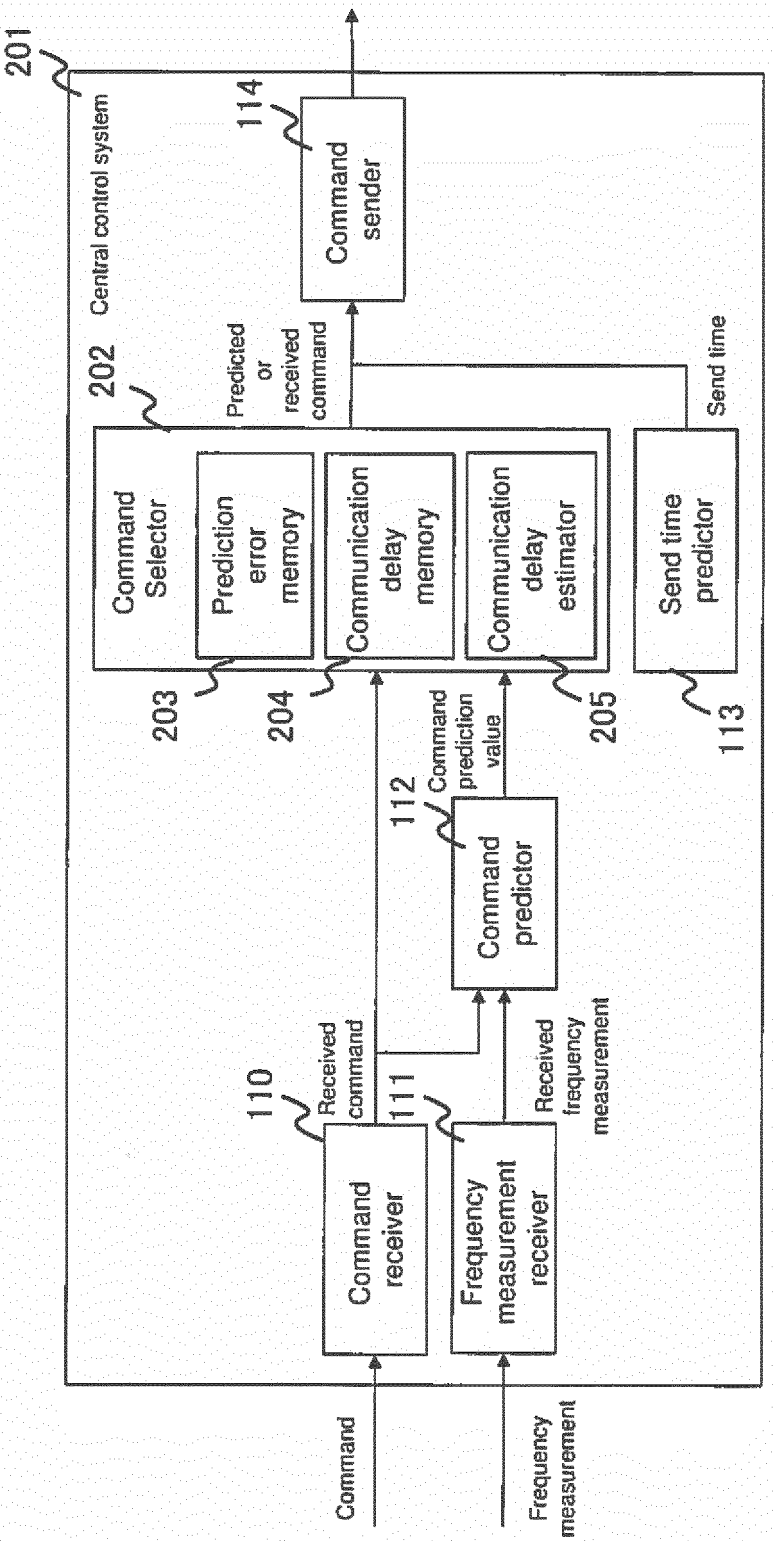

201
Central control system
114
Command sender
202
Predicted or received command
Send time
Command Selector
Prediction error memory
Communication delay memory
Communication delay estimator
Send time predictor
203
204
205
113
112
Command prediction value
Command predictor
110
Received command
111
Received frequency measurement
Command receiver
Frequency measurement receiver
Command
Frequency measurement

FIG. 8

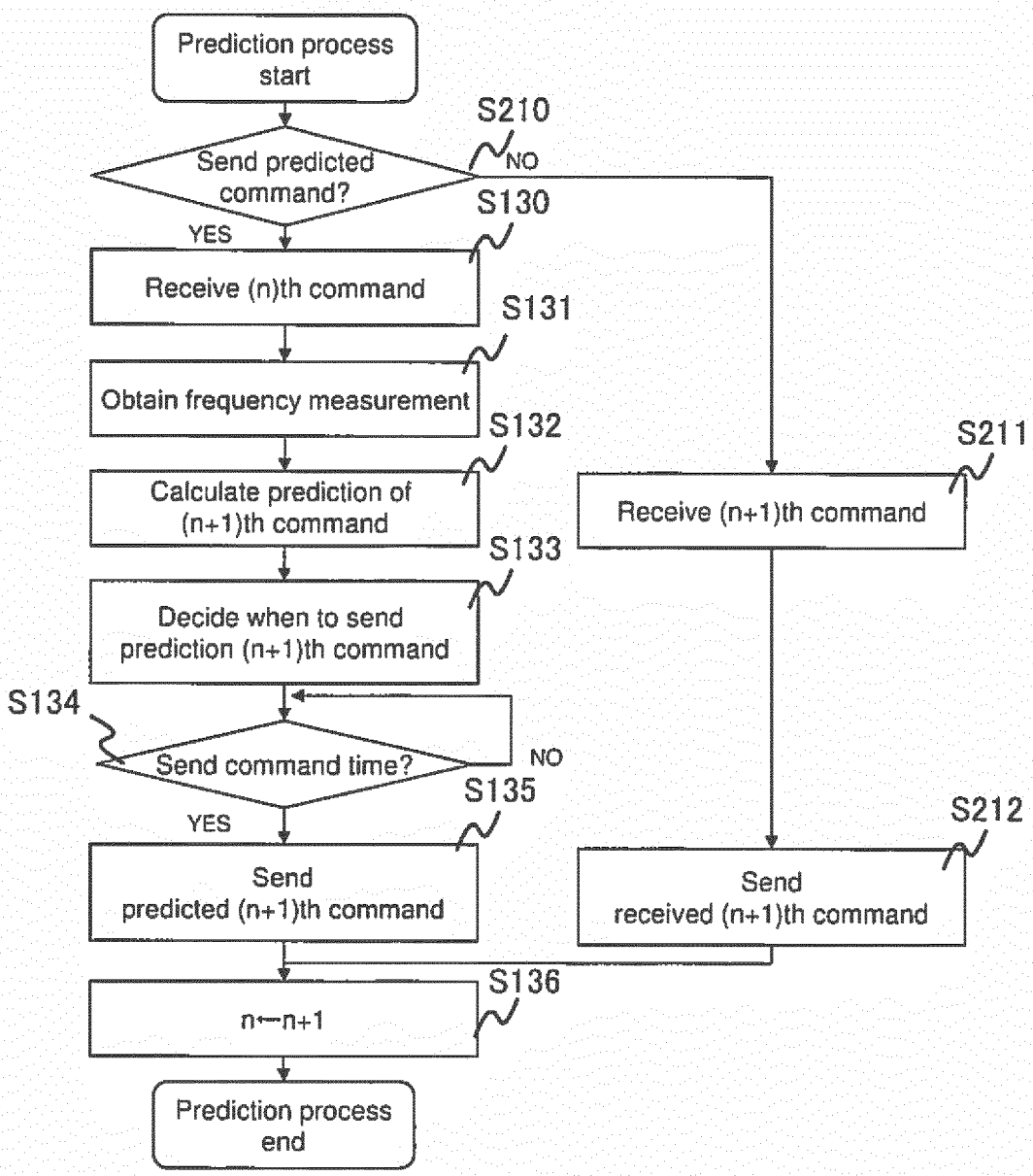

Prediction process start
S210
Send predicted command?
NO
YES
S130
Receive (n)th command
S131
Obtain frequency measurement
S132
Calculate prediction of (n+1)th command
S133
Decide when to send prediction (n+1)th command
S134
Send command time?
NO
YES
S135
Send predicted (n+1)th command
S211
Receive (n+1)th command
S212
Send received (n+1)th command
S136
n←n+1
Prediction process end

FIG. 9

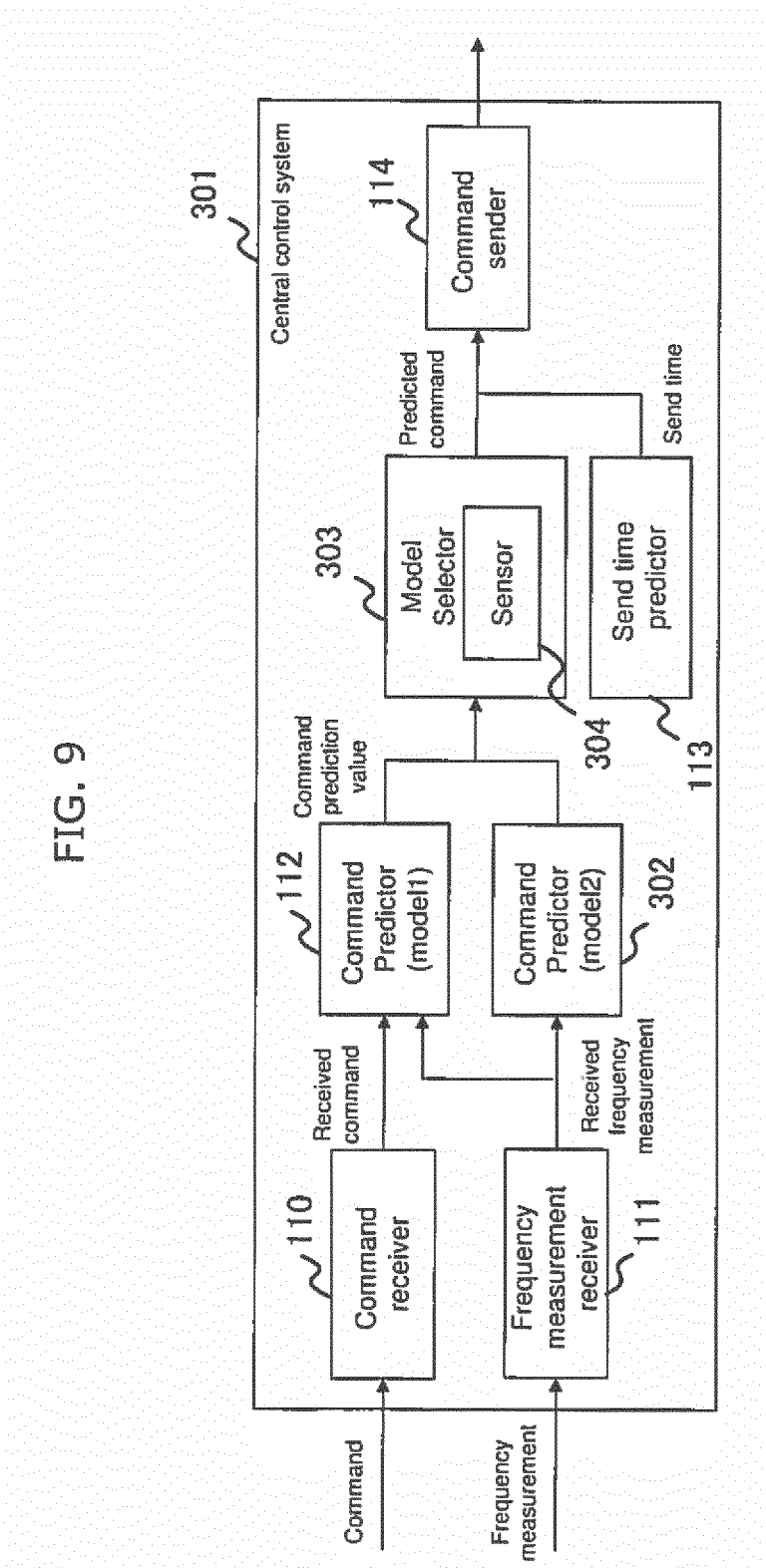

301
Central control system
114
Command sender
Predicted command
Send time
303
Model Selector
Sensor
Send time predictor
304
113
Command prediction value
112
Command Predictor (model1)
Command Predictor (model2)
302
Received command
Received frequency measurement
110
Command receiver
Frequency measurement receiver
111
Command
Frequency measurement

FIG. 10

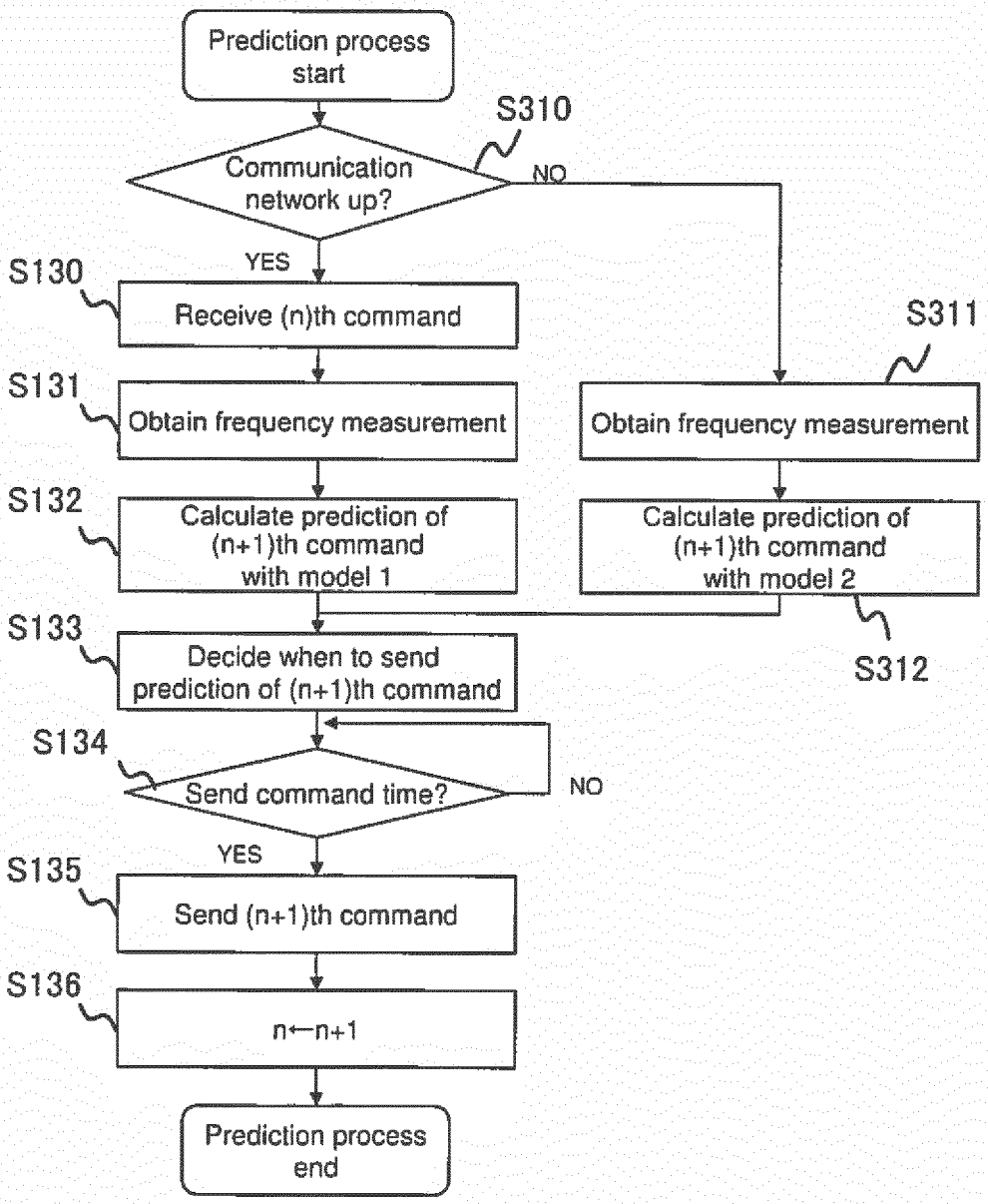

Prediction process start
S310
Communication network up?
NO
YES
S130
Receive (n)th command
S131
Obtain frequency measurement
S132
Calculate prediction of (n+1)th command with model 1
S311
Obtain frequency measurement
Calculate prediction of (n+1)th command with model 2
S312
S133
Decide when to send prediction of (n+1)th command
S134
Send command time?
NO
YES
S135
Send (n+1)th command
S136
n←n+1
Prediction process end

FIG. 11

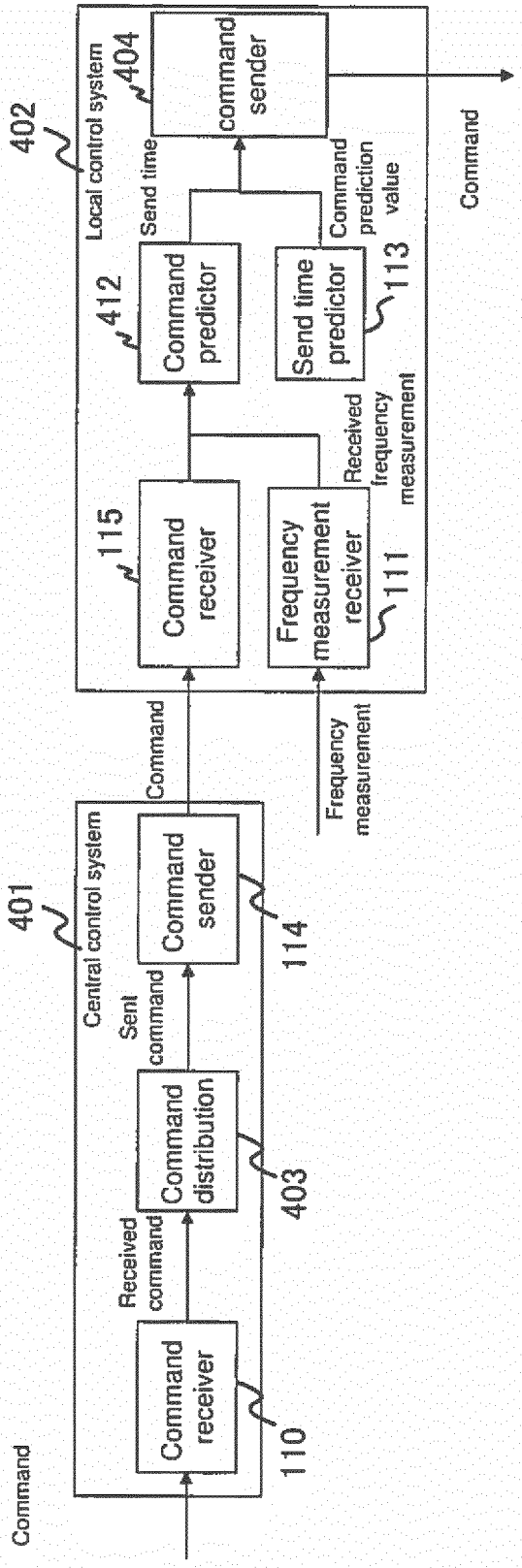
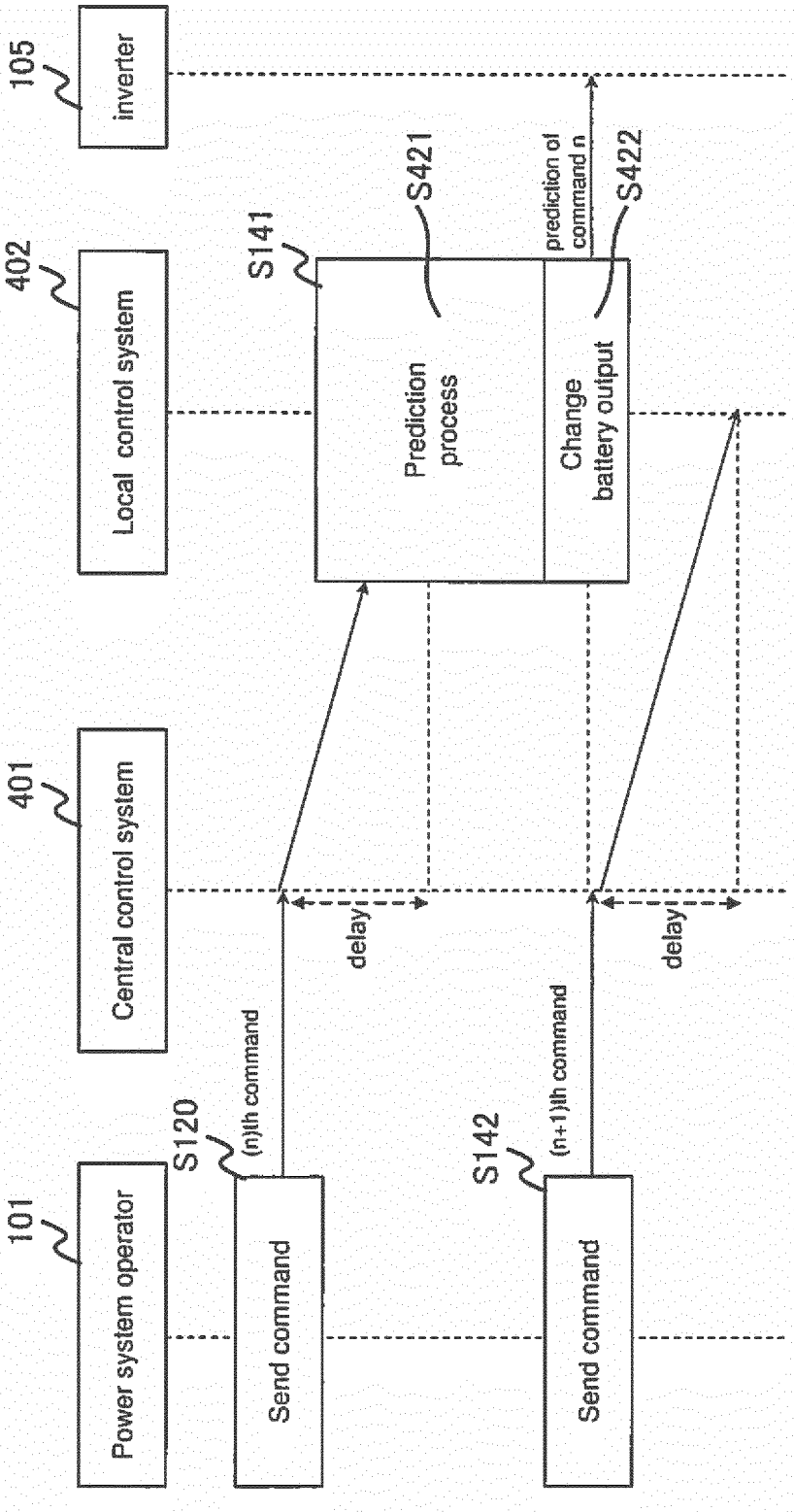

Command
110
Command receiver
Received command
403
Command distribution
Sent command
Central control system
401
Command sender
114
Command
Frequency measurement
Local control system
402
115
Command receiver
412
Command predictor
Send time
404
command sender
Command
Frequency measurement receiver
111
Received frequency measurement
Send time predictor
113
Command prediction value
Command

FIG. 12


105
inverter
402
Local control system
S141
S421
Prediction process
prediction of command n
S422
Change battery output
401
Central control system
delay
delay
101
Power system operator
S120
(n)th command
Send command
S142
(n+1)th command
Send command

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

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- US 2012323389 A **[0005]**